Climate Analysis from Ten Years of Radio Occultation Data

Chi Ao

Jet Propulsion Laboratory

California Institute of Technology, Pasadena

Contributors: Stephen Leroy, Olga Verkhoglyadova, Amanda Hajj, Jonathan Jiang, Tony Mannucci, Hui Su, Chengxing Zhai

CLARREO Science Team Meeting, April 16-18, 2013, Hampton, VA

Outline

1. Monitoring the width of the tropical belt using RO
2. Comparison of geopotential heights between RO, reanalyses, and CMIP5 models

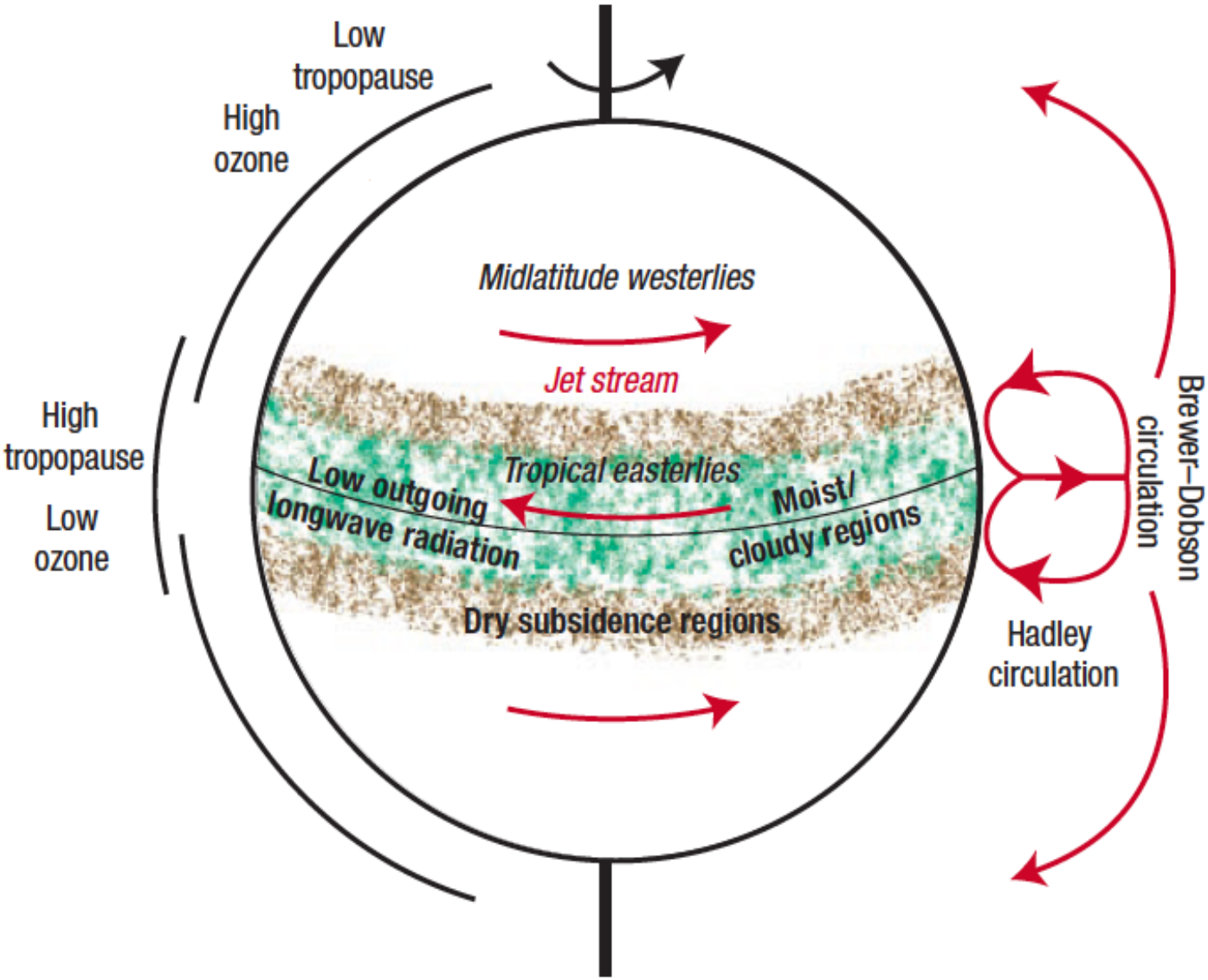
Part I

1. Monitoring the width of the tropical belt using RO
   - Defining width of the tropics (Hadley circulation) from tropopause height
   - Trends from the past decade
2. Comparison of geopotential heights between RO, reanalyses, and CMIP5 models

Motivation

- How does the general circulation change under global warming?
- Observational/modeling evidence suggests that the width of the tropics has been expanding in the past 3 decades.
- Even a small shift of the tropical boundaries can have significant societal impact.
- *Considerable uncertainty exists on the magnitude of the expansion and the physical mechanisms.*

Observational Metrics



Source: Seidel et al., Nature, 2008

TABLE 1 Estimates of tropical widening (in degrees latitude per decade) from observation-based studies

Study	Indicator	Data	Widening
Rosenlof [13]	Tropical upwelling (60 hPa)	Analyses	3.0
Reichler and Held [14]	Tropopause height	Radiosonde	0.4
	Tropopause height	Reanalyses	0.7
Fu et al. [15]	Tropospheric temperatures	MSU	0.7
Hudson et al. [16]	Total ozone	TOMS	1.0 (NH only)
Seidel and Randel [17]	Tropopause height	Radiosonde, reanalyses	1.8–3.1
Hu and Fu [59]	Outgoing longwave radiation	Various satellite sensors	1.5
	Mean meridional circulation	Reanalyses	1.0
Archer and Caldeira [92]	Jet stream separation	Reanalyses	0.3
Seidel et al. [23]	Jet stream separation	Reanalyses	1.0

Climate models project only ~ 0.2 deg/decade in the 21st century under an extreme warming scenario (A2)

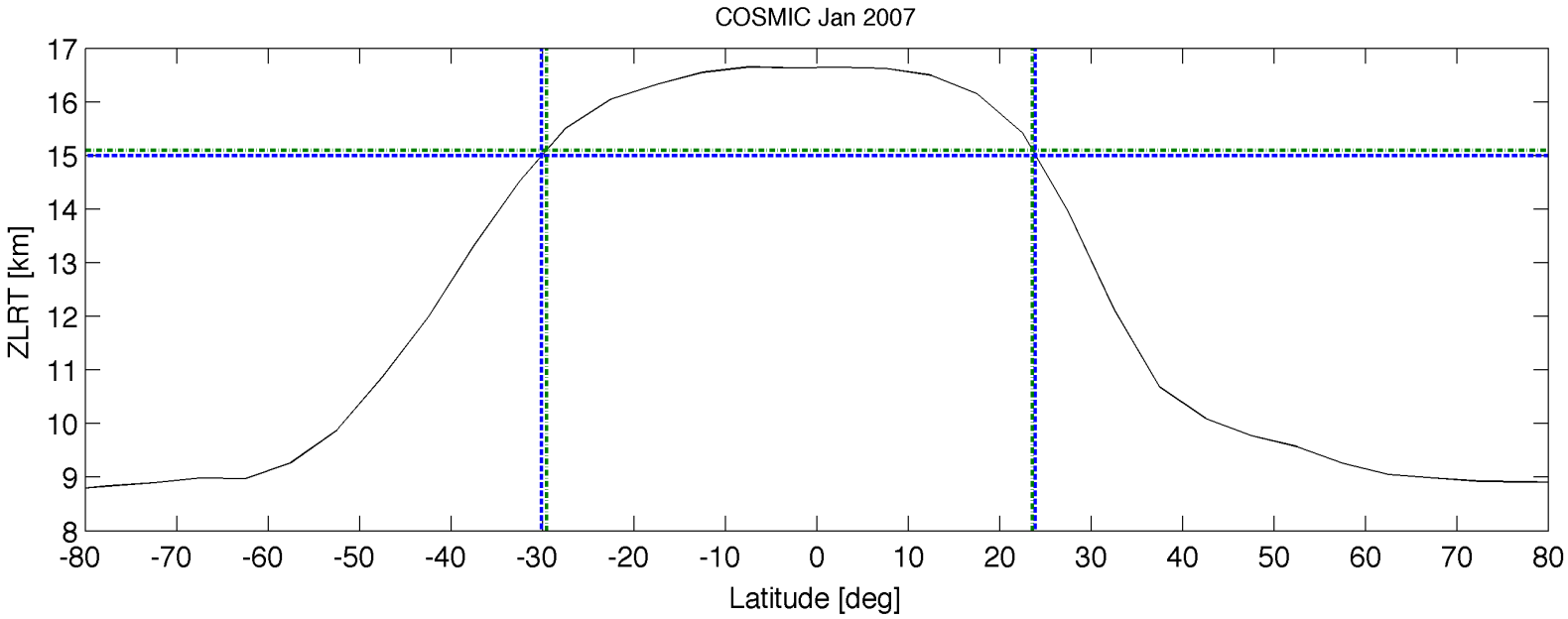
Source: T. Reichler, Changes in the Atmospheric Circulation as Indicator of Climate Change (2009)

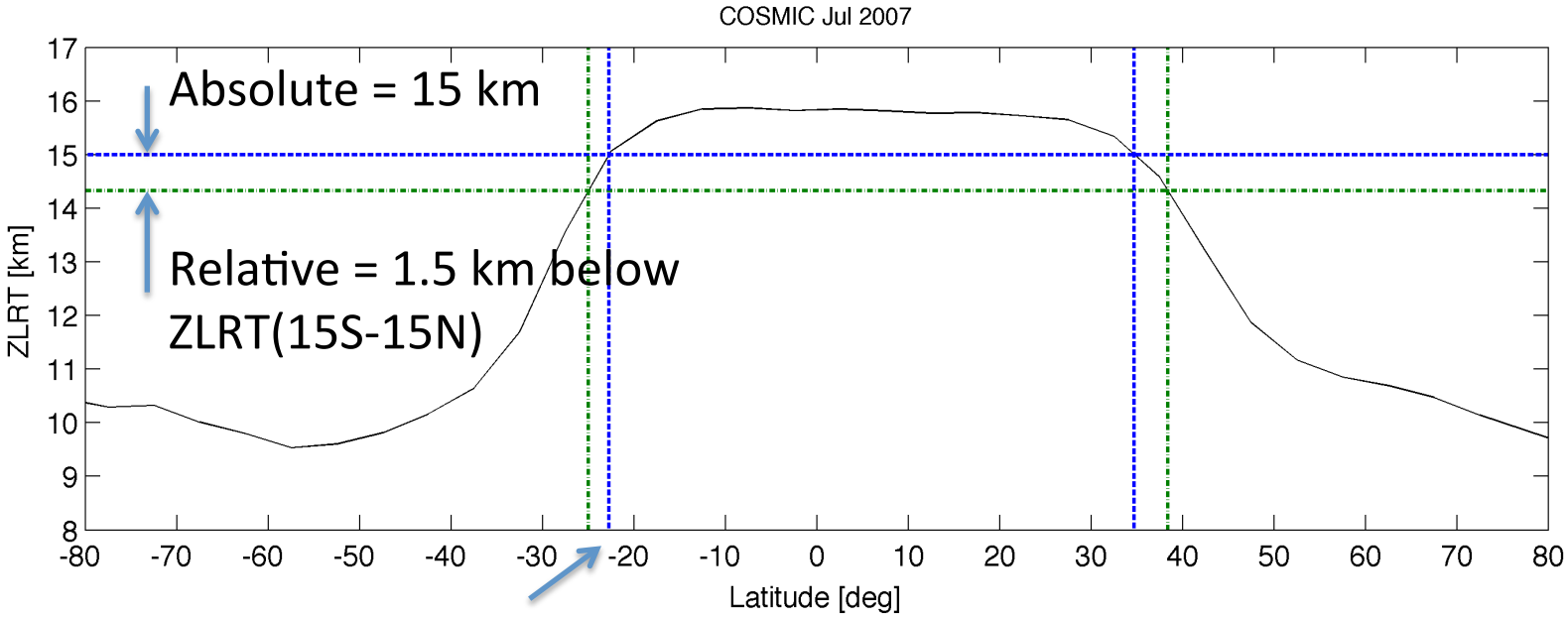
RO Tropopause Data Record

- > 10 yrs of temperature profiles
  - **CHAMP** (Apr. 2001 – Sept. 2008): 1 s/c, setting only, ~ 200 profiles/day.
  - **COSMIC** (June 2006 – present): 5-6 s/c, setting + rising, ~ 2000 profiles/day.
  - 0.2–0.5 K RMS accuracy in individual profile near the tropopause; < 0.2 K systematic error.
- Compute LRT height from each temperature profile.
- Obtain monthly zonal averages at 5-deg latitude bands.

Defining the Tropical Width with LRT Height

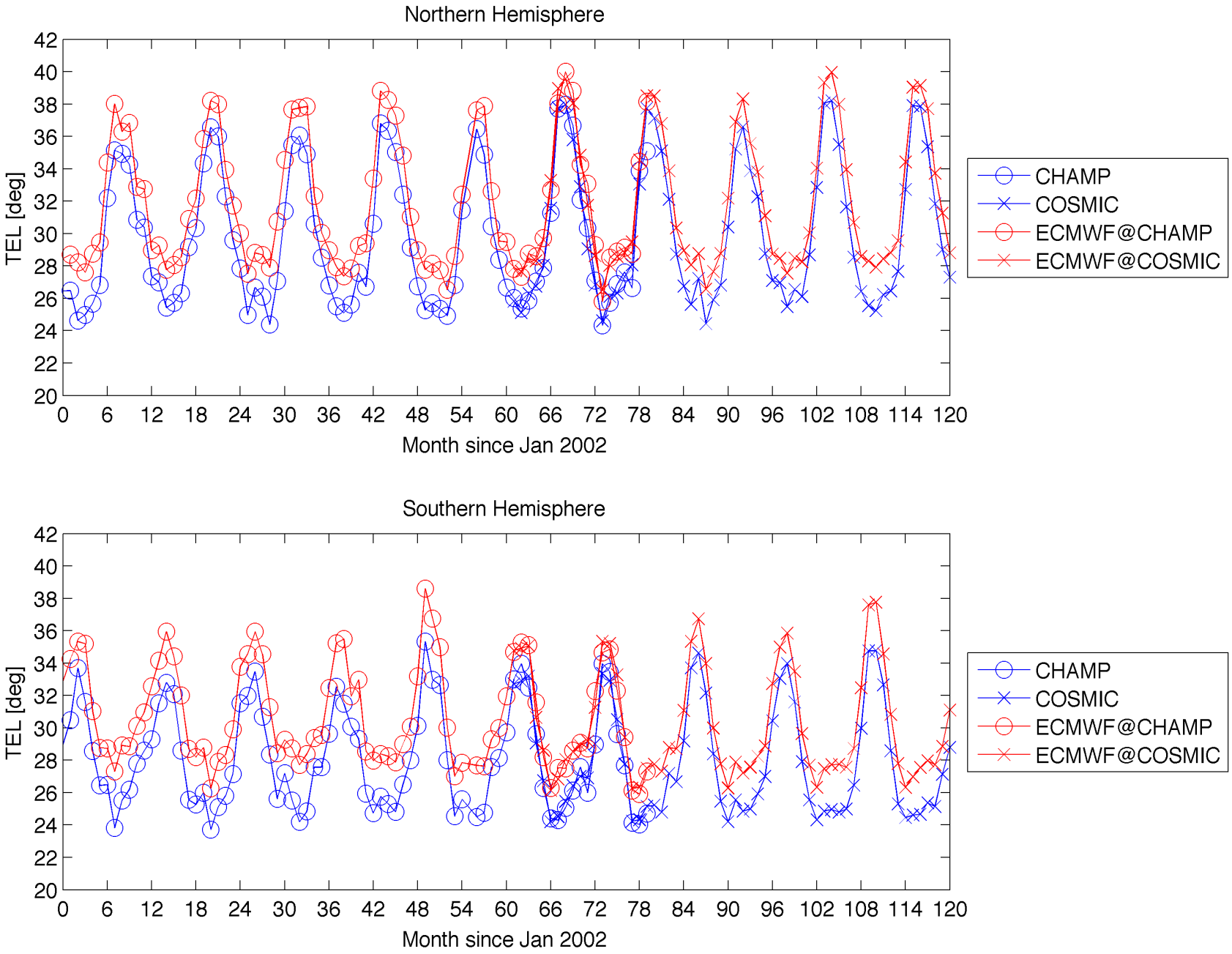
- LRT height in the tropics and extra-tropics have distinctly different values (~ 17 km vs. ~ 10 km).
  - **Seidel and Randel [2007]**: radiosonde and NCEP reanalysis; based on frequency of high tropopause values per year, uses two subjective criteria (frequency and height thresholds).
  - **Birner [2010]**: reanalyses; based on frequency distribution of tropopause heights; subjective (one height threshold criterion) and objective methods.
  - **Davis and Rosenlof [2012]**: reanalyses; based on height distribution; subjective (one height threshold) and objective methods.
- *We adopt the subjective **absolute and relative height threshold definitions** used in Davis and Rosenlof [2012].*



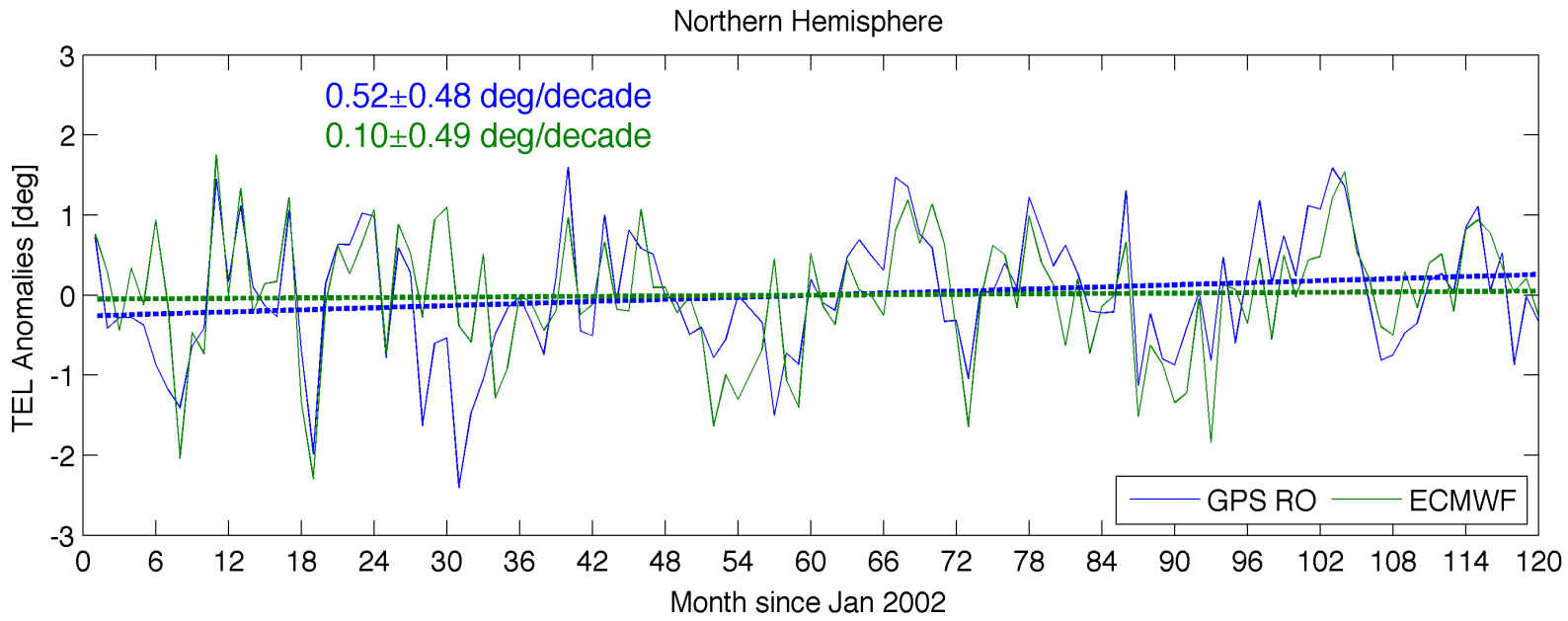


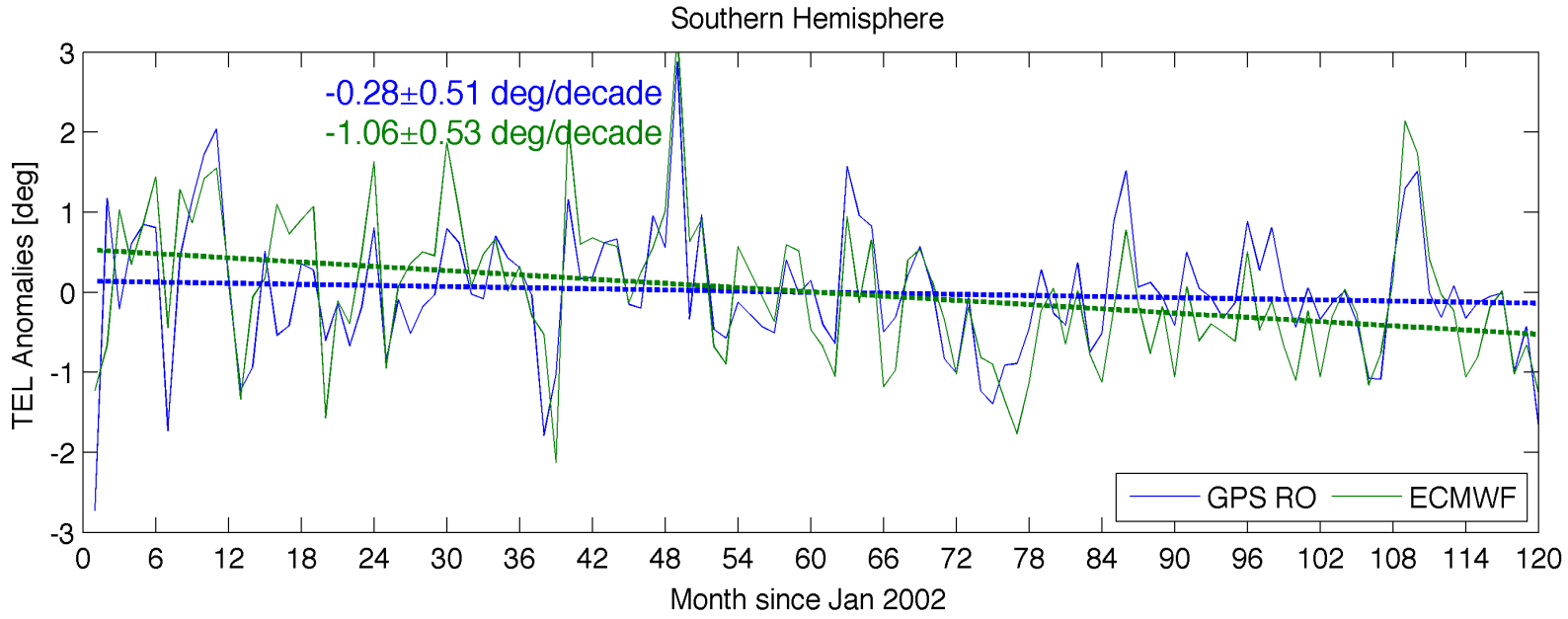
Tropical Edge Latitude (TEL)

Absolute threshold = 15 km

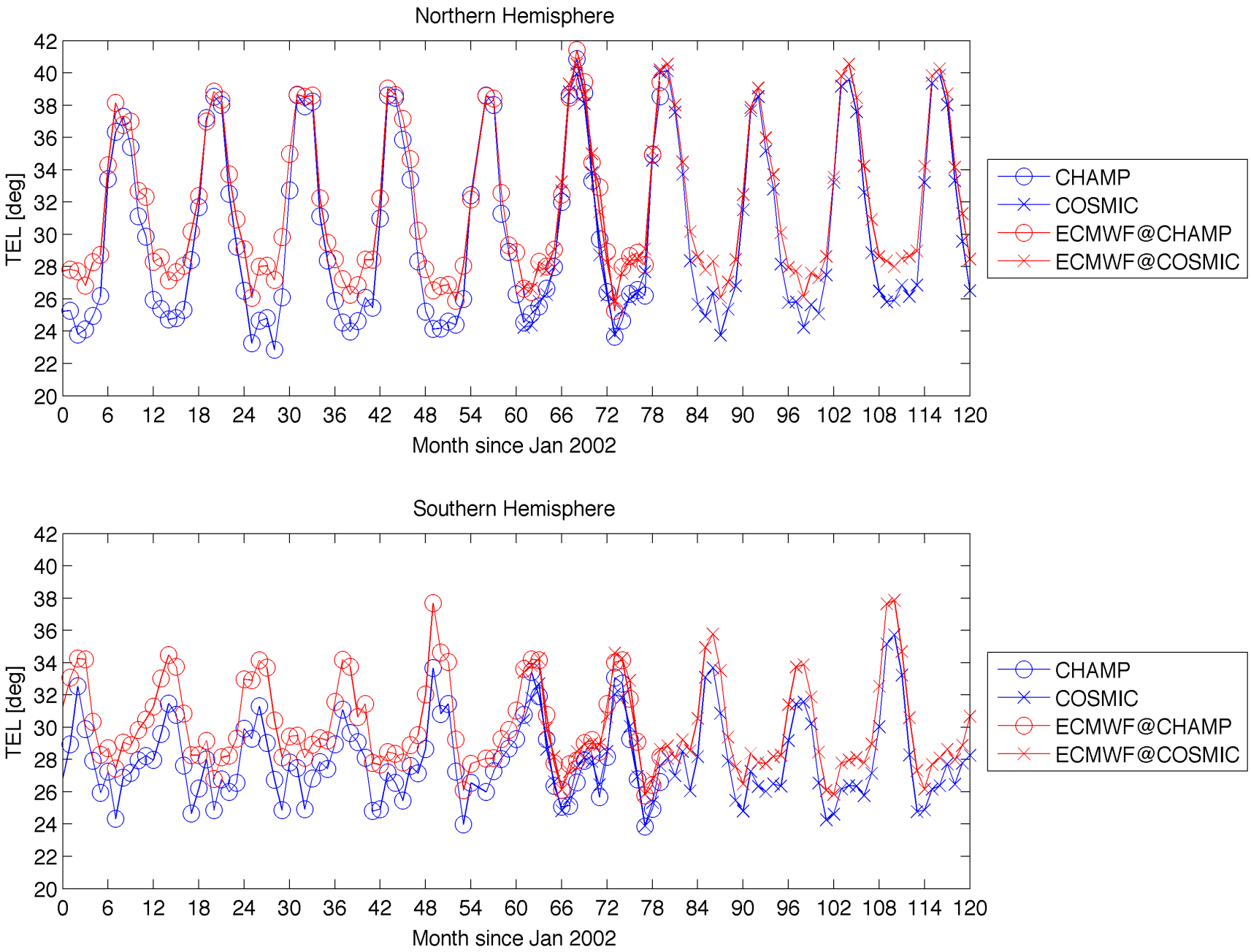


Absolute threshold = 15 km

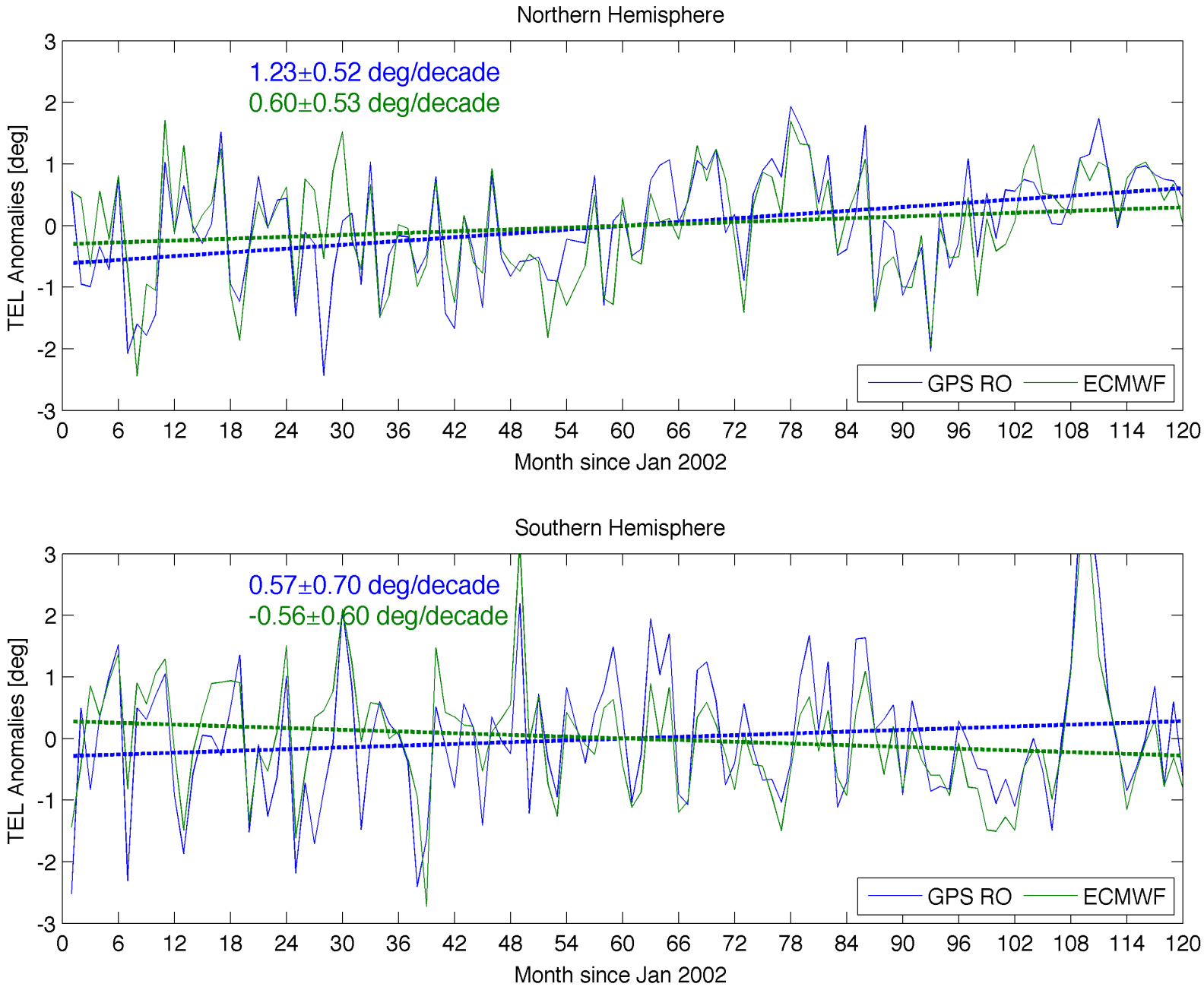




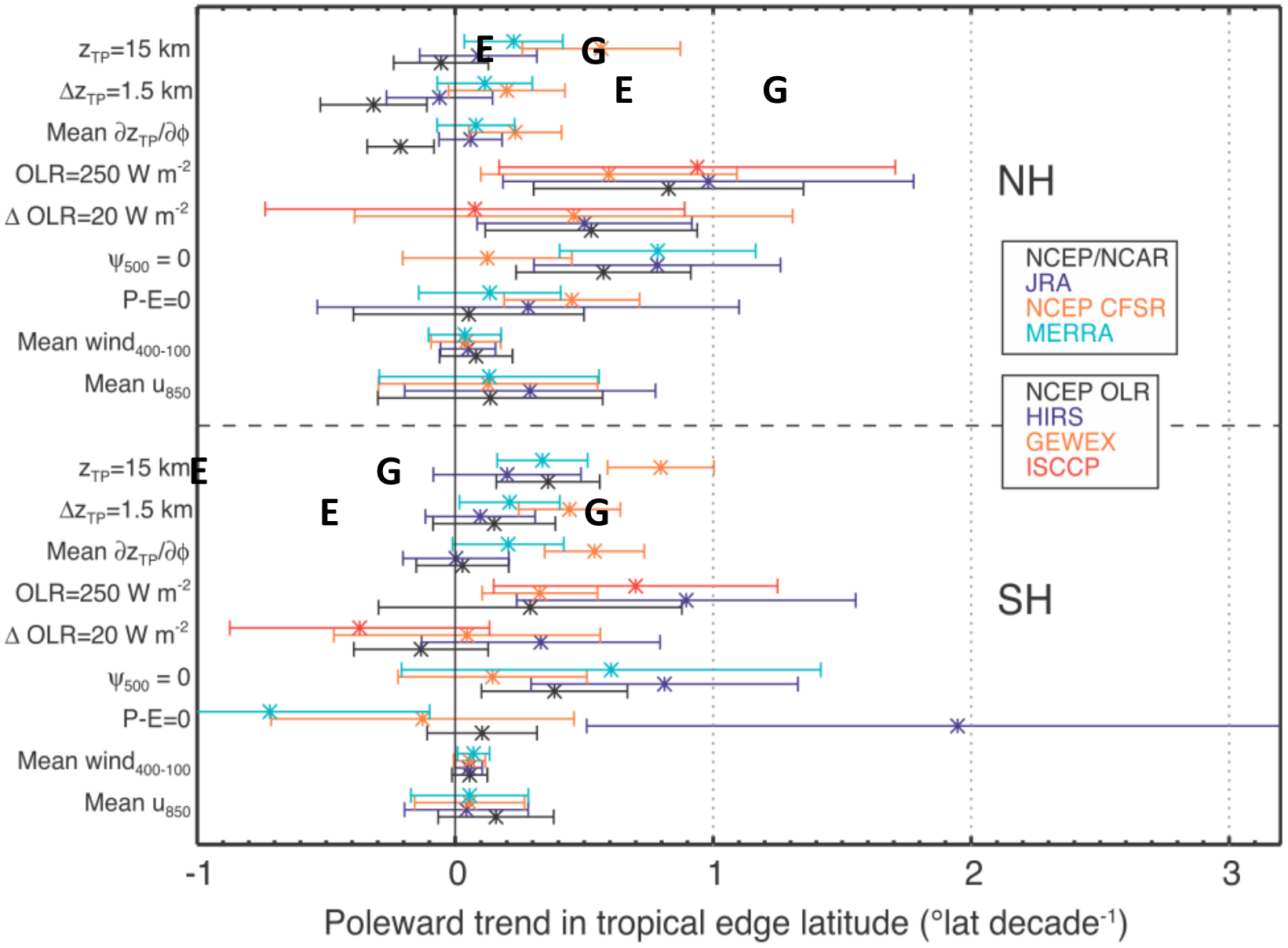
Relative threshold = 1.5 km



Relative threshold = 1.5 km

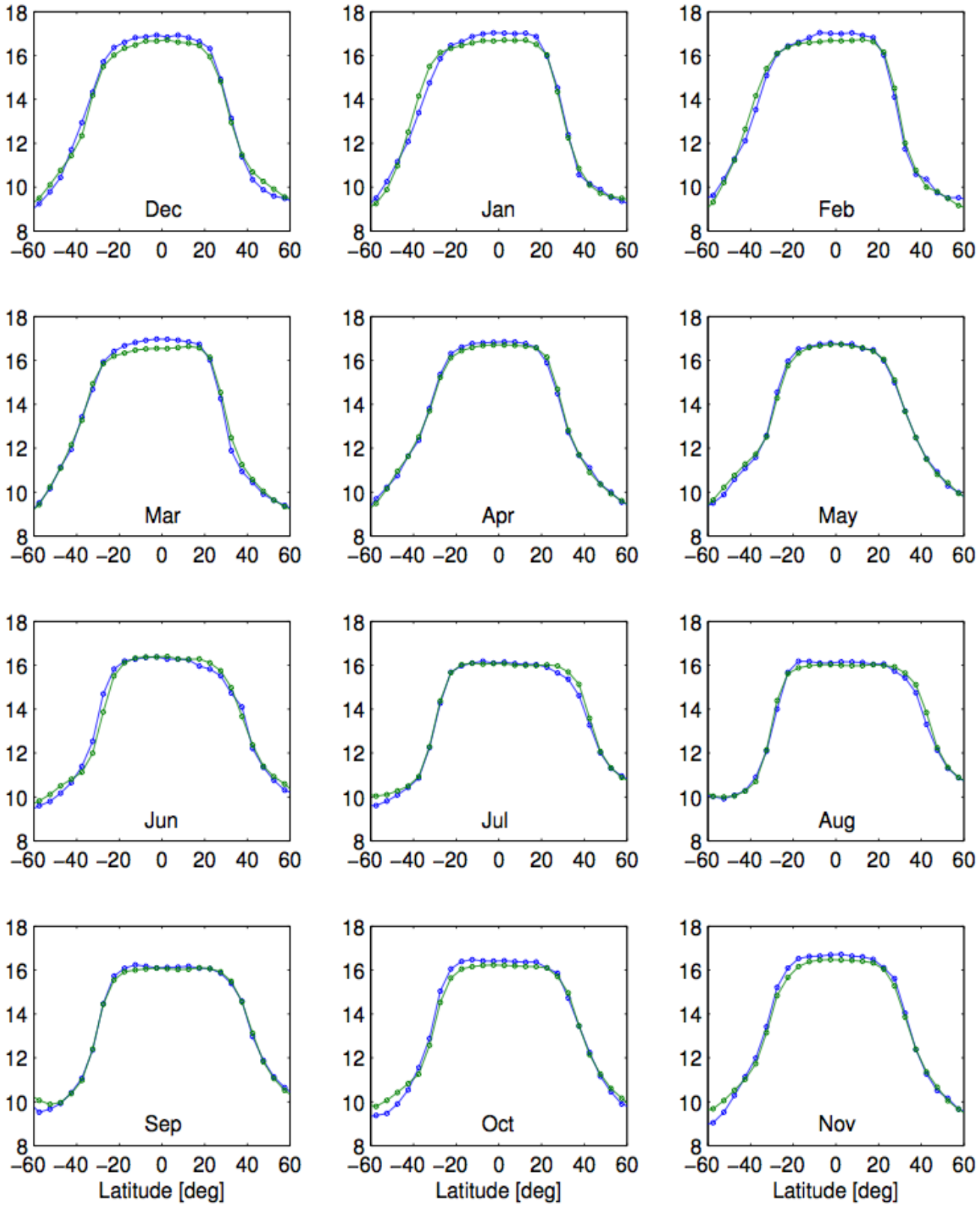


Davis and Rosenlof [2012] for period of 1979-1999



Changes in ZLRT from 2002 to 2011 based on linear fits

- Blue = beginning of period
- Green = end of period



Sensitivity to Vertical Resolution & Sampling

1. The LRT height is known to be sensitive to the vertical resolution of the temperature profile.
   - The results shown were based on 1-km vertical smoothing.
   - How would the inferred trends change without vertical smoothing (i.e. 200 m resolution)?
2. The transition from CHAMP to COSMIC introduce a significant change in sampling density (10x increase).
   - What if only one COSMIC s/c data was used?

Sensitivity to Vertical Resolution & Sampling

Table 1. Tropical widening rates for different vertical resolution and sampling density.

	1 km, all cosmic	200 m, all cosmic	1 km, cosmic4 only
NH (fix)	$\mathbf{0.75 \pm 0.50}$	$\mathbf{0.52 \pm 0.48}$	$\mathbf{0.75 \pm 0.52}$
SH (fix)	-0.23 ± 0.53	-0.28 ± 0.51	-0.09 ± 0.58
NH (rel)	$\mathbf{1.23 \pm 0.52}$	$\mathbf{1.12 \pm 0.51}$	$\mathbf{1.16 \pm 0.55}$
SH (rel)	0.57 ± 0.70	0.49 ± 0.70	0.64 ± 0.74

Conclusions (Part I)

- GPS RO tropopause heights provide observational monitoring of the tropical width.
- The widening rate is sensitive to the method used to define the tropical boundaries.
  - 0.5° lat/dec difference between the relative and absolute height definitions.
  - Also depends on vertical resolution & sampling, but not too sensitive for the relative height definition.
- A robust widening trend of ~ 0.5–1° lat/dec from 2002–2011 in NH has been detected. However, no statistical significant trend was found in the SH (ozone recovery?).

Part II

1. Monitoring the width of the tropical belt using RO
2. Comparison of geopotential heights between RO, reanalyses, and CMIP5 models

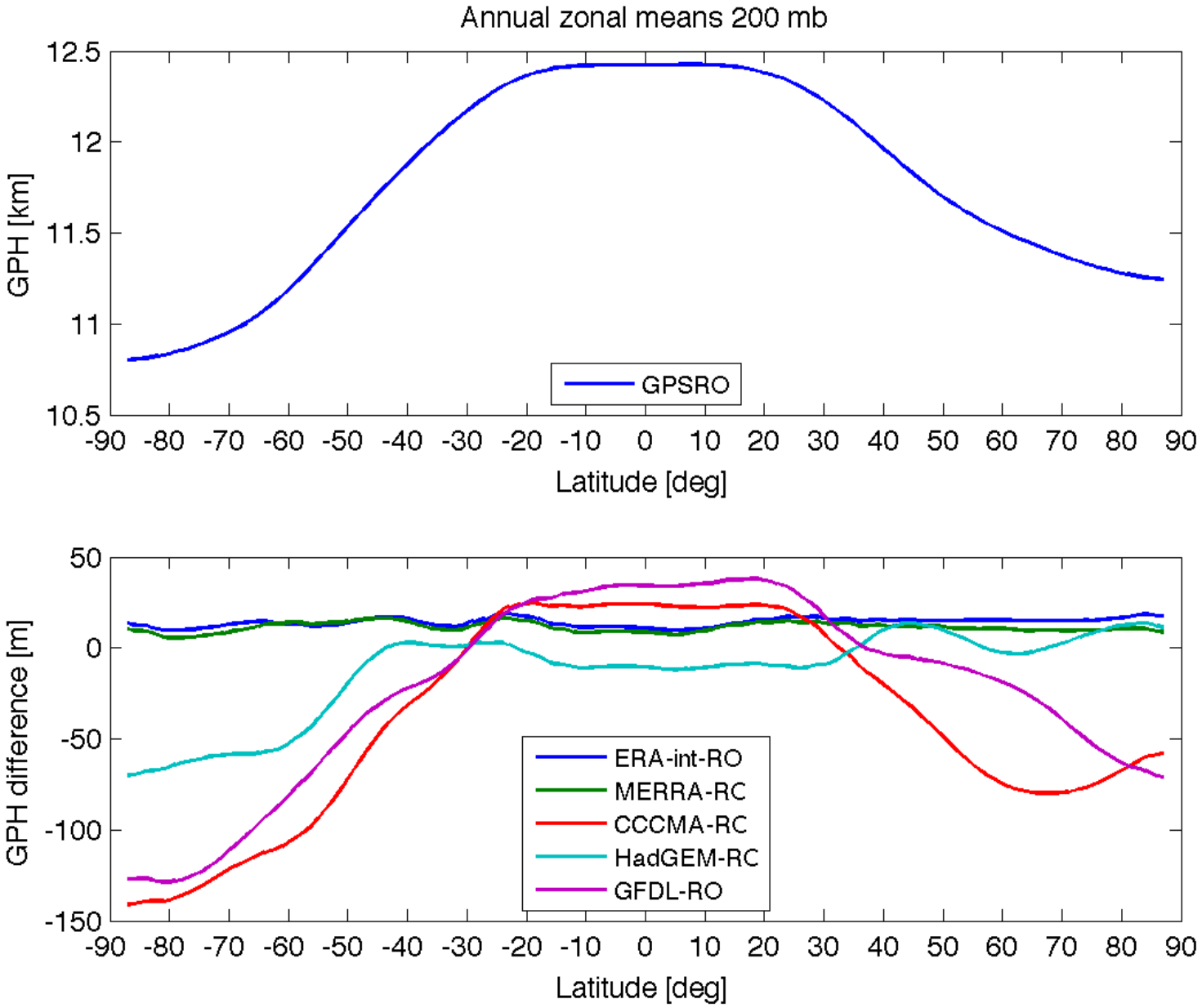
Data Used

- RO from CHAMP & COSMIC (2002–2011).
- ECMWF Reanalysis Interim and MERRA (2002–2011).
- 3 CMIP5 models (CCCMA, HadGEM2, GFDL). AMIP runs (imposed SST forcing). Overlap period with models is 2002–2008.
- Focus on 200 mb (average T over troposphere).

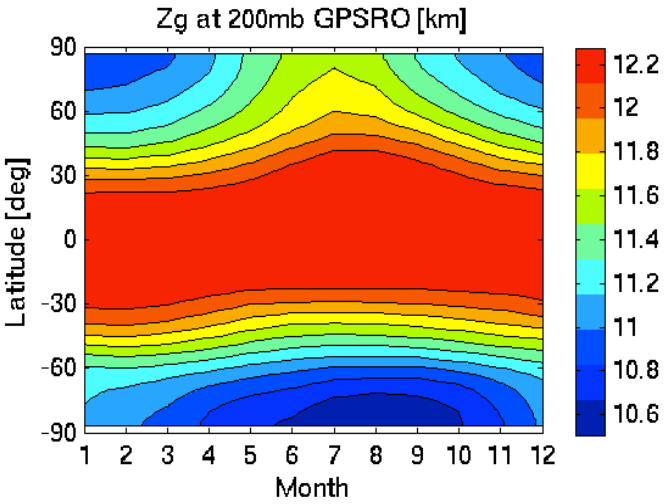
GPH Uncertainty

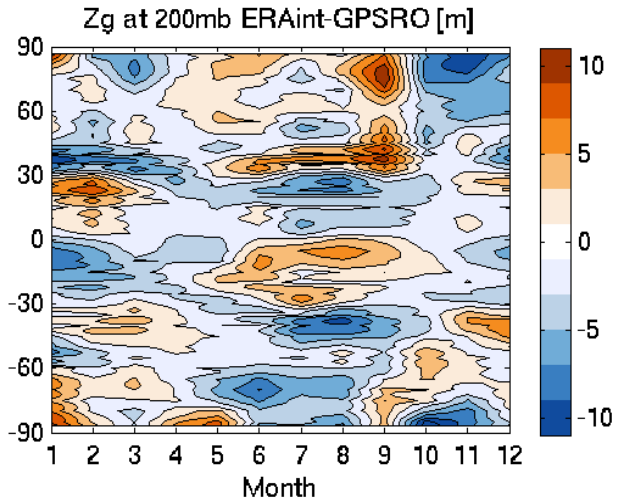
- Sampling errors [Leroy et al. 2012]:
  - Tropics: ~2 m (COSMIC), ~6 m (CHAMP)
  - Mid-latitudes: ~6 m (COSMIC), ~14 m (CHAMP)
- Systematic error [Kursinski et al. 1997]:
  - < 5 m at 200 mb

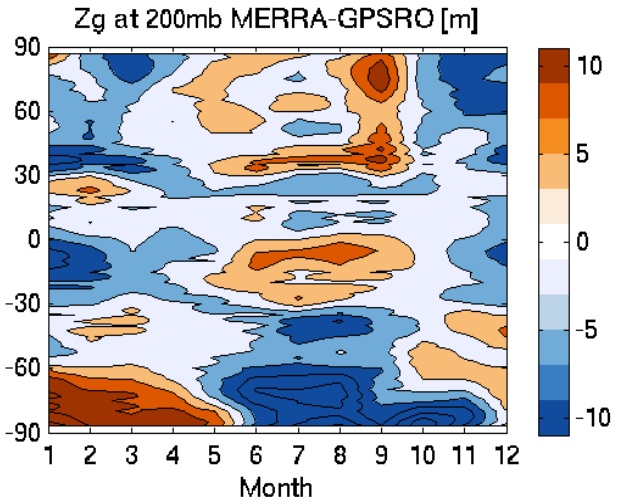
Annual Means (2002–2008)

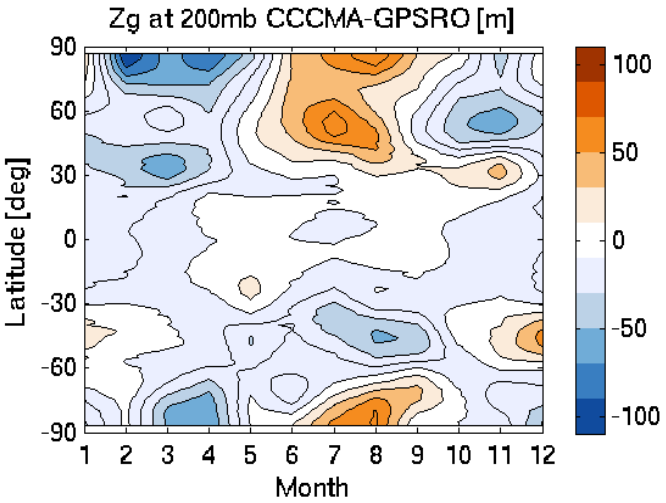


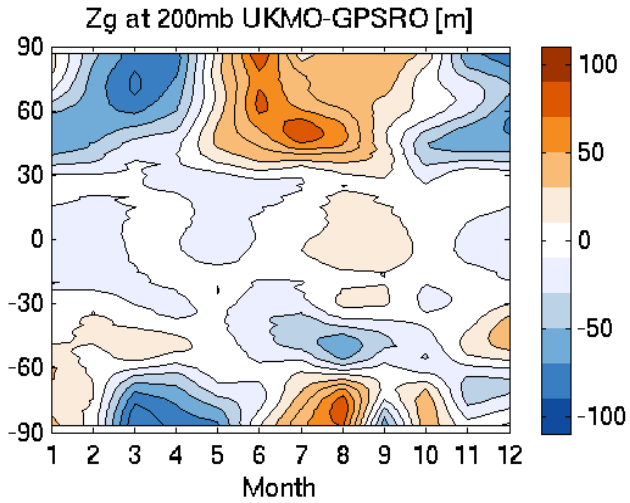
Seasonal Variability (2002–2008)

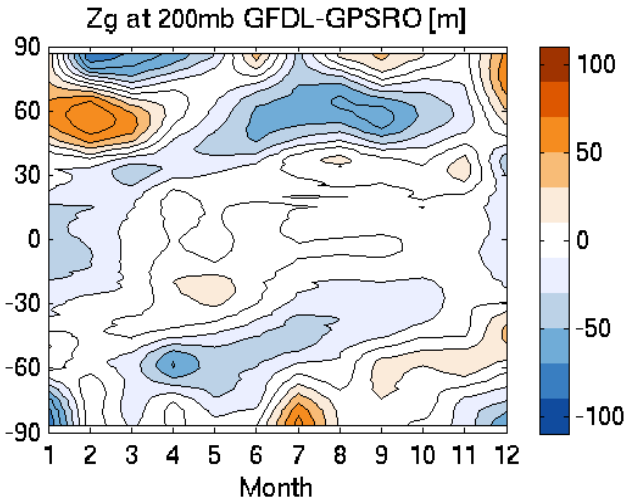




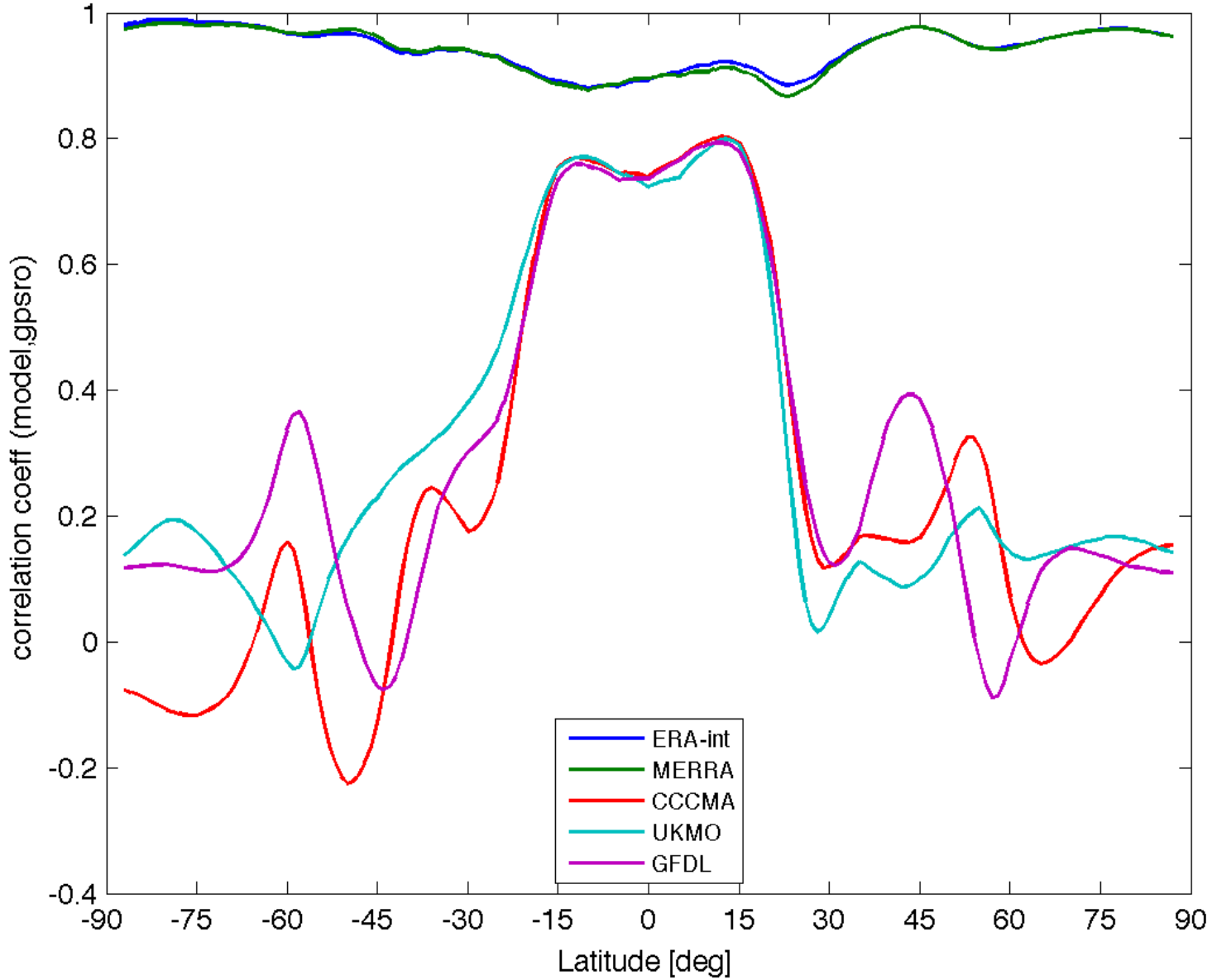




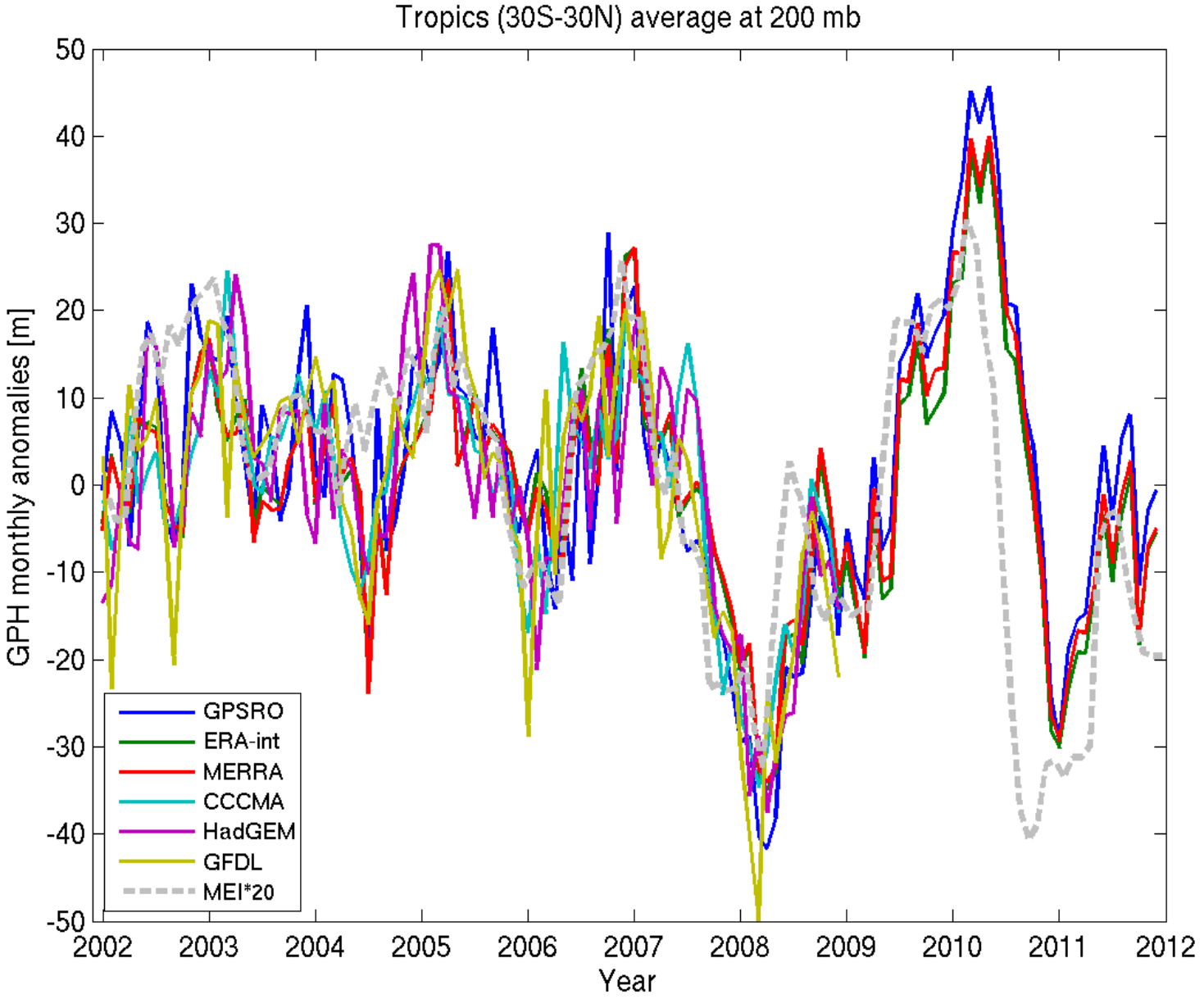




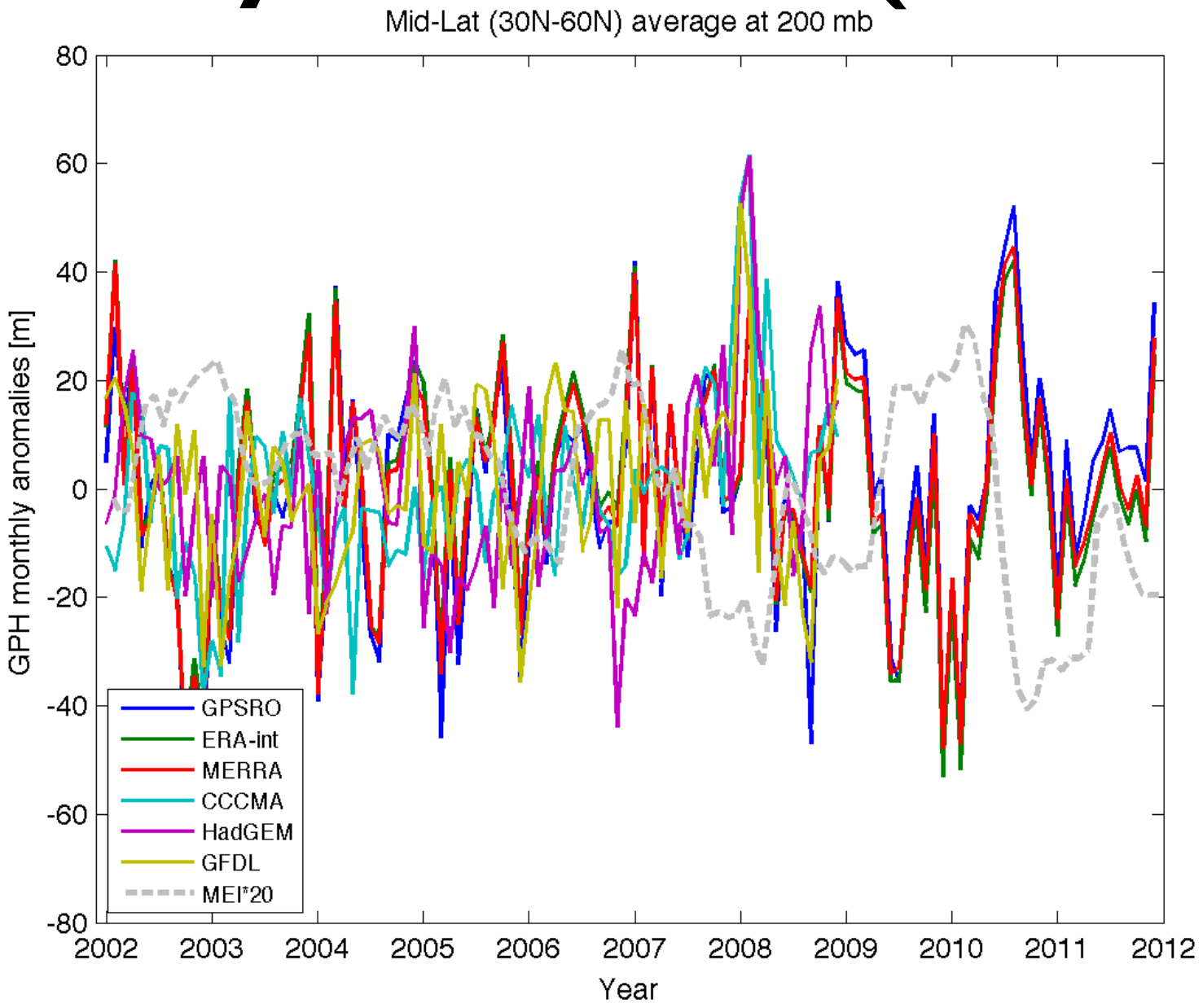
Correlation of Monthly Anomalies



Monthly Anomalies (Tropics)



Monthly Anomalies (Mid-Lat)



Conclusions (Part II)

- Geopotential height (200 mb) comparisons between GPS RO with reanalyses and CMIP5 models reveal systematic differences in both seasonal and interannual variabilities.
- RO and reanalyses:
    - Very good agreement (< 10 m). MERRA seasonal variability too large near South Pole.
    - RO produces larger anomalies in the tropics due to incomplete diurnal cycle sampling (CHAMP era).
- RO and models:
    - Good agreement between RO and models in the tropics (driven by imposed SST).
    - Strong disagreement in the extratropics (both seasonal/interannual).